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**FINAL REPORT
REUSABLE LAUNCH VEHICLE
RELIABILITY, MAINTAINABILITY AND
OPERABILITY ASSESSMENT**

MARCH 15, 1995

CONTRACT NAS8-39210
DR-4
DCN 1-1-PP-02147



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Reusable Launch Vehicle Reliability, Maintainability and Operability Assessment

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Prepared by: T.F. Weber Jr.

ROCKWELL SPACE SYSTEMS DIVISION

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Introduction

Rockwell's Space Systems Division was funded to conduct thorough Reliability, Maintainability & Operability (RM&O) assessments for 3 NASA conceptually-conceived SSTO vehicles; a Winged Body (WB001), a Vertical Lander (VL001) and, at some future time when input data becomes available, a Lifting Body. Rockwell was instructed to use their existing "generic" RM&O analysis models (MAtrix, SIMtrix & STARSIM), and apply them to the RLV vehicles of interest. The RM&O assessments were to encompass, as a minimum, the following parameters:

- MTBM (mean-time-between-maintenance)
- MTBR (mean-time-between-removal)
- MTBF (mean-time-between-failure)
- MTBCF (mean-time-before-critical-failure)
- MTTR (mean-time-to-repair)
- Probability of Mission Success
- Turnaround time
- Crew Size per Repair
- Manhours per Repair, and Manhours per Mission
- Flight Rate Capability
- Availability
- Downtime per Mission
- Manhours per Processing Flow (scheduled and unscheduled)
- Facility Utilization

Additionally, the MAtrix Model was to be exercised for the existing Space Shuttle and its infrastructure in order to judge the "reasonableness" of the SSTO RM&O estimates, and to provide a basis for comparing these SSTO estimates to "observed" Shuttle experiences. Fully operable Reliability & Maintainability Models for WB001, VL001 and the Space Shuttle were electronically transmitted to MSFC on December 13, 1994.

SUMMARY OF FINDINGS

Table 1

	PARAMETER	UNIT OF MEASURE	WB001	VL001	SHUTTLE	COMMENTS
1	Vehicle Turnaround Timelines	Days	24	28	70	See Figures 3 & 4
2	MTBF (mean-time-between-failure)	Flight Hours	8.88	7.47	2.90	Matrix outputs
3	MTBR (mean-time-between-removal)	Flight Hours	16.29	13.56	4.71	Matrix outputs
4	MTBM (mean-time-between-maintenance)	Flight Hours	3.74	2.99	1.25	Matrix outputs
5	MTTR (mean-time-to-repair)	Elapsed Hours	4.23	4.16	42.28	
6	MTBCF (mean-time-before-critical-failure)	Flight Hours	8735	7258	8247	Calculated From Probability of Mission Success
7	Benign Failure Analysis	Probability	-	-	-	See Tables 2 & 3
8	Critical Failure Analysis	Probability	-	-	-	See Tables 2 & 3
9	Probability of Mission Success (POMS)	Probability	0.98095	0.97712	0.97983	Matrix outputs
10	Crew Size per Repair	No. of People	3.88	3.90	5.68	
11	Manhours per Repair	Manhours	16.41	16.22	240.15	
12	Manhours per Mission (Unscheduled)	Manhours	3,966	5,151	147,233	
13	Annual Flight Rate per Vehicle @ 7 days each	Flights/Year	9.09	7.69	2.98	
14	Vehicle Availability (Based on Flight Rate)	Percentage	40.23	41.00	42.85	Availability results are discussed on Page 10
15	Manhours per Flow (Unscheduled)	Manhours	3,966	5,151	147,233	
16	Manhours per Flow (Scheduled)	Manhours	1,071	1,391	120,473	See Figure 6
17	Downtime per Mission	Elapsed Hours	576	672	1,680	
18	Direct Labor Force Size	No. of People	50	50	2,500	
19	Depot Maintenance Downtime Frequency	As Indicated	20 Flights	20 Flights	44 months	
20	Depot Maintenance Downtime Duration	Months	3	3	6	
21	Depot Maintenance Downtime Crew Size	No. of People	110	135	325	Based on Vehicle Reliability
22	Facility Utilization	Percentage	-	-	-	See Table 10

An Overview of Matrix, SIMtrix and STARSIM

Matrix is an EXCEL-based tool for investigating the Reliability and Maintainability potentials of conceptually-defined spacecraft (reusable launch vehicles, satellites, interplanetary probes, etc.). Matrix functions with a minimum amount of input data, yet provides credible and useful outputs. A simplified flow diagram is presented as Figure 1.

As a required part of the contractual effort herein reported, Reliability & Maintainability Models were developed for the Winged Body design (WB001), the Vertical Lander (VL001), and the Space Shuttle. These models, and selected outputs of interest to MSFC, were separately provided in accordance with an agreed-upon submittal schedule.

Matrix offers these advantages:

1. Requires, as inputs, only the limited design data typically available during conceptual and preliminary design studies.
2. Uses R&M "k" factors, at the system and component levels, derived from and directly traceable to observed and reported R&M experience data for a broad range of aircraft systems, and for Space Shuttle systems as well.
3. Its ease of use enables it to be used in "real time" (i.e., in consonance with the on-going design process). Matrix outputs can be made available within a matter of minutes following a change in design or operational plan.
4. Uses environmental adjustment factors based on those provided by MIL-HDBK-217. These factors are used to account for the stress differences that exist during various mission phases, i.e., launch and re-entry, on-orbit, while in a ground-based maintenance facility (like the OPF), etc.
5. Is sensitive to the cycle-dependent or operating time-dependent nature of each system and component. For example, Landing Gear maintenance is a direct result of the number of landings made, not flight duration.
6. Initially determines the important parameter, UMA/FH (Unscheduled Maintenance Actions per Flying Hour). From this fundamental parameter the rates of removal, failure and critical (aborting) failure are determined using USAF and Shuttle - derived ratios for systems and components "like" those used on the SSTD vehicles.
7. Can be operated at successfully deeper WBS levels as design information becomes available at those levels.

MATRIX Flow Diagram (Simplified)

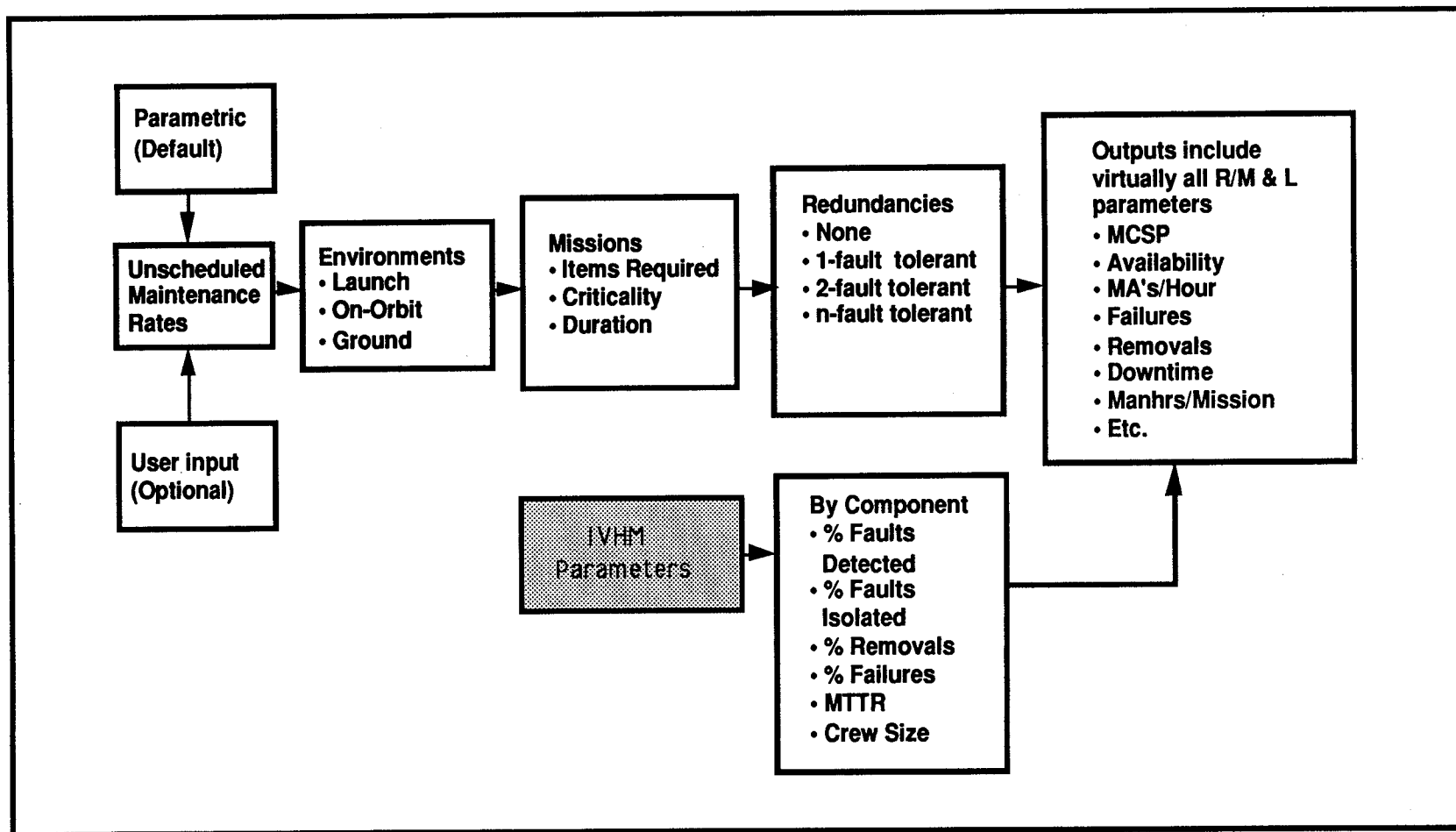


Figure 1

SIMtrix Overview

SIMtrix is a generic name for a family of GPSS-based Monte-Carlo simulation models. One version is used to assess the minute-by-minute ascent (and descent) reliabilities of multi-engined rocket propulsion systems. The inherent power of simulation enables this tool to investigate complex problems dealing with engine-out situations, when they are most likely to occur, the effect of varying thrust levels, descent engine in-flight start probabilities, etc.

A "typical" use of this model involves a sample size of 50,000 ascents. The mission is arbitrarily subdivided into 10 time increments of about 40 seconds each. Each of the 7 (or 8) engines is "tested" twice for failure (once for benign failure and once for catastrophic failure) during each time increment, thus it follows that $50,000 \times 7 \times 10 \times 2 = 7,000,000$ individual "tests" per run are conducted. Using the PC version of GPSS, run time is about 3 hours for the complete sample of 50,000 ascents.

A second version of **SIMtrix** simulates vehicle downtime by considering each possible unscheduled maintenance task (as identified by **MATRIX**), and the elapsed time and manpower required to accomplish each. Repair times are randomly selected from a log-normal distribution of times (each vehicle system has its own unique, empirically-derived distribution). An attempt is made to draw designated personnel quantities from a manpower pool, and work commences if the required personnel are available for use (the size of the manpower pool is a user variable). Work will be delayed if personnel quantities are insufficient.

Another user-controlled variable is the number of tasks that can be conducted simultaneously on the vehicle. The vehicle's access provisions and safety considerations limit the number of technicians that feasibly can be on, in or around the vehicle at the same time.

Downtime is the elapsed time from start of the first task to completion of the last, and varies as a function of reliability, repair times and their distributions, personnel available, accessibility and safety considerations. Typically, 500 missions are simulated per "trial", where (for the RLV's studied) each "trial" encompassed 125,000 to 150,000 separately modeled unscheduled maintenance actions. A 500 mission simulation requires about 10 minutes of computer time using the PC version of GPSS.

Results of the many downtime simulation test cases run are discussed throughout this report.

Modeling Main Propulsion System Reliability Using SIMtrix

SIMtrix examines engine reliability at selected time intervals during ascent, descent or both. Each engine is separately modeled. At each carefully selected time interval (nominally about 40 seconds) the analyst can introduce reliability changes. For example, assume a thrust increase is scheduled to take place following the third time interval. During the next time interval a per-engine reliability value appropriate to the increased thrust level replaces the per-engine reliability value used for the first 3 intervals. Similarly, it may be necessary to increase thrust on all remaining engines following an in-flight shutdown of one of them. SIMtrix, knowing in what time interval the shutdown took place, advances the throttles on the remaining engines (thus introducing lower reliability values) for the duration of the ascent (or descent). Using this same approach it is possible to model non-constant reliability.

Figure 2 depicts SSME-derived catastrophic and benign MTBFs. These MTBFs were converted to the numerical reliability values subsequently used in SIMtrix.

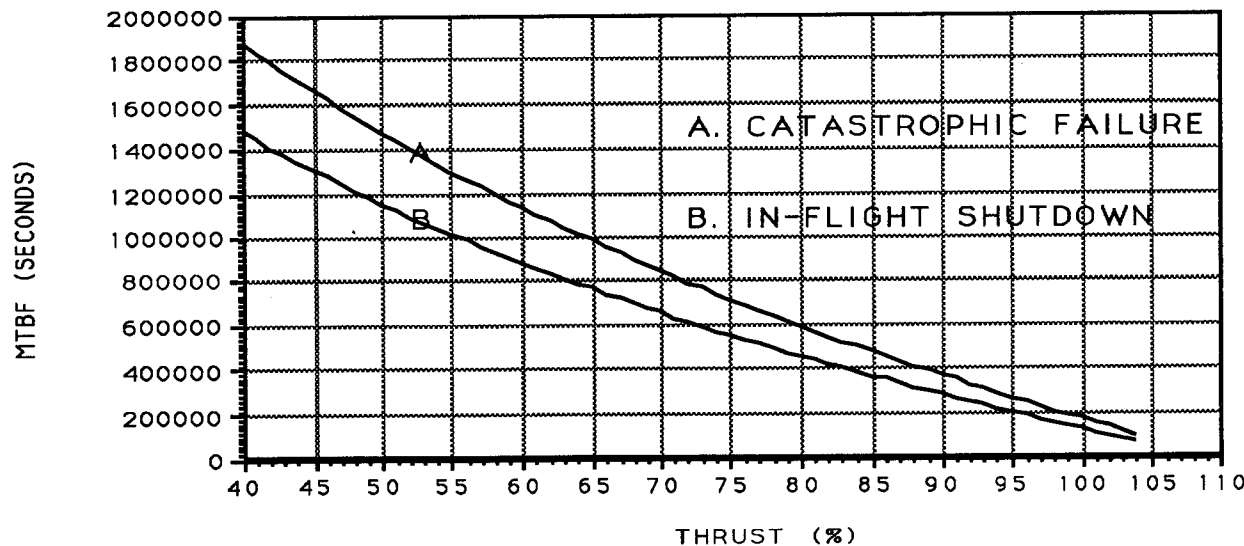


Figure 2. SSME-Derived Catastrophic & Benign MTBFs

Table 2 depicts WB001 Main Propulsion System Reliability as a function of how many CRIT 1 failures and in-flight shutdowns (IFSDs) occurred during each ascent increment, by engine. The average thrust per time increment is clearly indicated. For this analysis it was assumed that 7 of 7 engines were required for ascent, the 1st IFSD results in mission abort. Any CRIT 1 failure was deemed to be Catastrophic, and resulted in loss of vehicle. Results below were included in the WB001 Matrix Model.

Table 2. WB001 Main Propulsion System Reliability

ASCENT INCREMENT (SECONDS)	THRUST (%)	CRIT 1 FAILURES ENGINE #1	CRIT 1 FAILURES ENGINE #2	CRIT 1 FAILURES ENGINE #3	CRIT 1 FAILURES ENGINE #4	CRIT 1 FAILURES ENGINE #5	CRIT 1 FAILURES ENGINE #6	CRIT 1 FAILURES ENGINE #7	CRIT 1 FAILURES ALL ENGINES	7/7 REQUIRED FOR SAFE LANDING
20	100	5	8	5	4	6	6	2	36	BASED ON SAMPLE OF 50,000 FLIGHTS.
20	100	7	7	10	7	5	8	4	48	
20	100	8	5	5	7	9	8	5	47	
20	100	12	10	8	4	4	4	7	49	
60	100	14	18	20	18	14	12	12	108	
50	83	6	8	6	4	5	8	2	39	
181	40	5	4	3	8	6	6	2	34	
TOTALS =		57	60	57	52	49	52	34	361	R (CAT) = 0.992780
ASCENT INCREMENT (SECONDS)	THRUST (%)	1st IFSD ENGINE #1	1st IFSD ENGINE #2	1st IFSD ENGINE #3	1st IFSD ENGINE #4	1st IFSD ENGINE #5	1st IFSD ENGINE #6	1st IFSD ENGINE #7	1st IFSD ALL ENGINES	7/7 REQUIRED FOR MISSION SUCCESS
20	100	12	8	7	8	10	10	12	67	The 1st In-Flight Shutdown results in abort, and is tabulated here.
20	100	9	10	7	6	9	5	8	54	
20	100	8	13	7	8	13	9	7	65	
20	100	4	7	12	9	10	6	11	59	
60	100	18	32	18	24	25	19	29	165	
50	83	4	7	7	7	6	6	3	40	100% Thrust Used
181	40	7	4	11	12	8	5	8	55	Following Any IFSD
TOTALS =		62	81	69	74	81	60	78	505	R (IFSD) = 0.989827
										R (ALL) = 0.982680

Table 3 depicts VL001 Main Propulsion System Reliability as a function of how many CRIT 1 failures and in-flight shutdowns (IFSDs) occurred during each ascent and descent increment, by engine. The average thrust per time increment is clearly indicated. For this analysis it was assumed that 8 of 8 engines were required for ascent, the 1st IFSD results in mission abort. Any CRIT 1 failure was deemed to be Catastrophic, and resulted in loss of vehicle. For the descent segment of the mission, the probability of engine restart was assumed to be 0.990 per engine. Results below were included in the VL001 Matrix Model.

Table 3. VL001 Main Propulsion System Reliability

ASCENT INCREMENT (SECONDS)	THRUST (%)	CRIT 1 FAILURES ENGINE #1	CRIT 1 FAILURES ENGINE #2	CRIT 1 FAILURES ENGINE #3	CRIT 1 FAILURES ENGINE #4	CRIT 1 FAILURES ENGINE #5	CRIT 1 FAILURES ENGINE #6	CRIT 1 FAILURES ENGINE #7	CRIT 1 FAILURES ENGINE #8	CRIT 1 FAILURES ALL ENGINES	8 OF 8 REQUIRED FOR SAFE LANDING
20	100	6	7	6	6	4	5	9	4	47	BASED ON SAMPLE OF 50,000 FLIGHTS.
20	100	4	8	5	5	3	7	8	10	50	
20	100	7	5	5	5	6	5	2	3	38	
20	100	7	5	9	7	10	3	6	8	55	
60	100	24	10	14	14	17	18	10	19	126	
50	83	3	1	4	12	5	5	4	8	42	
181	40	6	3	4	6	6	3	5	6	39	
	ASCENT =	57	39	47	55	51	46	44	58	397	R (CRIT 1-ASCENT) = 0.992060
125	DESCENT =	12	12	12	13	8	15	15	19	106	R (CRIT 1-DESCENT) = 0.997841
											R (CRIT 1 -BOTH) = 0.989918
ASCENT INCREMENT (SECONDS)	THRUST (%)	1st IFSD ENGINE #1	1st IFSD ENGINE #2	1st IFSD ENGINE #3	1st IFSD ENGINE #4	1st IFSD ENGINE #5	1st IFSD ENGINE #6	1st IFSD ENGINE #7	1st IFSD ENGINE #8	1st IFSD ALL ENGINES	8/8 REQUIRED FOR ASCENT 100% Thrust Used Following Any IFSD
20	100	2	5	9	3	8	4	10	11	52	8 OF 8 REQUIRED FOR MISSION SUCCESS
20	100	7	7	13	8	4	11	6	6	62	
20	100	4	14	5	9	9	4	4	12	61	
20	100	8	5	7	5	9	10	12	3	59	
60	100	24	19	16	29	20	18	29	23	178	
50	83	7	7	10	6	6	5	2	4	47	The 1st Ascent In-Flight Shutdown results in abort, and is tabulated here.
181	40	6	7	7	5	4	3	5	6	43	
	ASCENT =	58	64	67	65	60	55	68	65	502	R (IFSD-ASCENT) = 0.989880
											4 OF 8 REQUIRED FOR DESCENT
125	DESCENT =	1	0	1	0	1	0	0	2	5	R (IFSD-DESCENT) = 0.999900
											R (ASCENT/DESCENT) = 0.979802

Rationale for Differences in Analysis Results Between the Space Shuttle and the RLVs

Quantitative RM&O analyses and assessments were completed for the Winged Body and Vertical Lander SSTOs, their major systems and components. Input data necessary for the assessment of the Lifting Body was not available. The Lifting Body RM&O analysis will be conducted at a later date.

The resultant quantitative RM&O assessments provide NASA with a "yardstick" for measuring the degree of RM&O inherent in their conceptual design configurations.

All configuration-related inputs to Matrix, the primary R&M analysis tool, were provided by MSFC. These inputs included vehicle mass properties, system descriptions, main engine thrust profiles, etc. Data such as RCS and OMS burn times were assumed to be similar to those of the Shuttle Orbiter, and were extracted from "Shuttle Flight Data and Inflight Anomaly List," JSC 19413.

RM&O outputs for the WB001 & VL001 Reusable Launch Vehicles are based on use of aircraft-type ground processes. Unlike the practice in use for the Shuttle, vehicle and system re-certification is not required prior to next flight, and ground testing is limited to only that which can be technically justified by a RCM (Reliability Centered Maintenance) - or similar, analysis. As a consequence, turnaround times are considerably shortened compared to Shuttle, and far fewer maintenance personnel are required.

Key parameters such as RLV Probability of Mission Success and Probability of Safe Landing are comparable to Shuttle. The factor which limits the WB001 and VL001 to Shuttle-level values is the number of RD-704 engines used in the Main Propulsion Systems (7 & 8 respectively). Although these engines were assumed to be at least as reliable as the Shuttle's SSMEs, all must operate satisfactorily for mission success. For Shuttle, all 3 SSMEs are required. Requiring successful operation of 7 engines for the WB001, or 8 of 8 for the VL001, are more demanding requirements.

Advanced 1990+ technologies to be incorporated in the design of the RLVs are expected to significantly improve system and component-level reliabilities (compared to the Shuttle's 1970+ technologies). RLV MTTRs (the frequency-weighted average of system and component MTTRs) are much improved compared to Shuttle. It was assumed that an aggressive Maintainability Program would be in effect during RLV development. While there is no inherent reason why "aircraft-type" MTTRs can't be realized, it was conservatively assumed that RLV MTTRs and maintenance crew sizes would be twice those of contemporary aircraft.

Rationale for Differences ... Continued

The level of availability achieved by a vehicle is a function of its Reliability, Maintainability and Supportability, and its utilization rate. It can be shown that, for a given vehicle, availability will decrease as utilization rate is increased (assuming that average flight duration remains the same). Table 1, Item 14 (Vehicle Availability) indicates that the availabilities of the WB001 and VL001 RLVs were found to be lower than that of the Shuttle. This result is consistent with how availability is measured, i.e., the RLVs will be considerably more reliable, maintainable and supportable than the present Shuttle and, as a consequence, can be used more frequently. Due to their higher annual utilization rate, RLVs will have more downtime hours per year than the Shuttle, thus their availability will be lower. If the RLVs were to be utilized at the Shuttle flight rate of 2.98 flights per year per vehicle, their availabilities would be; Shuttle = 42.85%, WB001 = 80.41% and VL001 = 77.14%

Avionic System reliabilities, from a Probability of Mission Success perspective, for WB001, VL001 and the Orbiter are seen to be appreciably better than the Avionic System reliabilities thus far realized by Expendable Launch Vehicles such as Atlas, Delta and Titan. For example, it can be shown that the MTBCF for Atlas avionics is about 11 mission hours, for Delta the avionics MTBCF is about 21 mission hours and for Titan avionics, MTBCF is about 63 hours. In contrast, the MTBCF for Orbiter avionics is greater than 7,000 mission hours. Compared to ELVs, the Orbiter's higher level of avionics redundancy is the principal reason for the dramatic differences. Similarly high MTBCFs for RLVs should be expected, for the same reason.

A major output of MAtrix is RLV Probability of Mission Success (POMS). POMS has been estimated for the WB001, VL001 and Shuttle, and for their major systems. Estimates are provided in Tables 4 - 9. The missions for which these estimates apply include all aspects of RLV launch, ascent, on-orbit operations, re-entry and landing. Mission duration is 168 elapsed hours (liftoff to landing roll-out). On-orbit operations such as rendezvous and docking with Space Station have not been considered in the POMS analysis. However, the effect of such operations on POMS is considered to be minimal. Docking device reliability needs to be considered in order to determine POMS for such a mission.

Note 1. The Probabilities of Mission Success and Safe Landing for the "boxed" components of Tables 4 - 9 are indicated as being 1.0, or very close to it. This does not necessarily mean that their reliabilities also approximate 1.0. For the "boxed" components, not all failures are Mission or Flight Critical. Consider also that (1) not every component is required for successful or safe mission completion, and (2) in all likelihood, alternate means will be available to perform the required functions. Greater design definition is required before the effects of potential redundancy levels, and other mission critical issues, can be fully assessed, although it is expected that success probabilities will, in fact, be exceedingly high. Aircraft-derived MTBCFs were employed for structural components, landing gear, etc.

Table 4. Summary Matrix Outputs for WB001

WB001 REUSABLE LAUNCH VEHICLE Matrix INPUTS/OUTPUTS (1/25/95)	INPUT IN SHADED AREA
OPERATIONAL INPUTS ...	
RD-704 BURN TIME (HRS) =	0.103
FLIGHT DURATION (HRS) =	168.000
FLIGHT NO. (1 - 20+) =	20
Not Used =	2
OMS BURN TIME (HRS) =	0.140
WB001 SUMMARY OUTPUTS ... (Note: Flight-based excludes TPS Tiles/Blankets)	
UMAs/MISSION (FLIGHT-BASED) =	44.96
REMOVALS/MISSION (FLIGHT-BASED) =	10.31
FAILURES/MISSION (FLIGHT-BASED) =	18.92
TOTAL OPF-INDUCED PRs/FLOW (INCLUDING TPS) =	136
TOTAL OPF-INDUCED FAILURES/FLOW =	6
FAILURES/MISSION (LAUNCH PAD) =	1.12
TPS DEBRIS IMPACT REPAIRS/MISSION =	60
TPS PRs PER FLOW =	58
UNSCHEDULED MANHOURS PER FLOW =	3,966
SCHEDULED MANHOURS PER FLOW =	1,071
WB001 RLV ESTIMATED RELIABILITY	
PROBABILITY OF MISSION SUCCESS =	0.98095
PROBABILITY OF SAFE LANDING =	0.99104

Table 5. WB001 Matrix Inputs & Outputs (Selected)

VEHICLE	WB001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
	WING GROUP	-	-	10823					1.5549744	0.2055458
	EXPOSED WING SURFACE	1	9281	9281	0.999859659	0.999859659	0.999859659	0.999859659	1.3333320	0.1762592
	CARRY-THROUGH	1	1542	1542	0.999976670	0.999836332	0.999976670	0.999836332	0.2216424	0.0292866
	TAIL GROUP	-	-	1902					0.2731680	0.0361228
	FIN	1	1902	1902	0.999971246	0.999807583	0.999971246	0.999807583	0.2731680	0.0361228
	BODY GROUP	-	-	62857					9.0431880	1.1937472
	LH2 TANK	-	-	15781					2.2759800	0.2997022
	STRUCTURE	1	14028	14028	0.999786960	0.999594584	0.999786960	0.999594584	2.0240976	0.2664104
	INSULATION	1	1753	1753	0.999973487	0.999568082	0.999973487	0.999568082	0.2518824	0.0332918
	RP-1 TANK	-	-	3279					0.4708704	0.0622744
	STRUCTURE	2	1389.5	2779	0.999957996	0.999526096	0.999957996	0.999526096	0.3990504	0.0527782
	INSULATION	2	250	500	0.999992439	0.999518538	0.999992439	0.999518538	0.0718200	0.0094962
	LO2 TANK	-	-	12579					1.8123000	0.2388946
	STRUCTURE	1	11542	11542	0.999824924	0.999343547	0.999824924	0.999343547	1.6633680	0.2191992
	INSULATION	1	1037	1037	0.999984323	0.999327880	0.999984323	0.999327880	0.1489320	0.0196954
	BASIC STRUCTURE	-	-	19024					2.7328392	0.3612964
	NOSE SECTION	1	461	461	0.999993030	0.999320915	0.999993030	0.999320915	0.0662256	0.0087552
	INTERTANK	1	6677	6677	0.999898952	0.999219935	0.999898952	0.999219935	0.9600024	0.1268060
	AFT BODY/THRUST STRUCTURE	1	3630	3630	0.999945082	0.999165060	0.999945082	0.999165060	0.5217408	0.0689396
	THRUST STRUCTURE CONE	1	6847	6847	0.999896589	0.999061736	0.999896589	0.999061736	0.9824640	0.1300360
	ENGINE BAY	1	1409	1409	0.999978694	0.999040450	0.999978694	0.999040450	0.2024064	0.0267596
	SECONDARY STRUCTURE	-	-	12194					1.7511984	0.2315796
	PAYLOAD BAY DOOR	1	2100	2100	0.999968251	0.999008731	0.999968251	0.999008731	0.3016104	0.0398810
	PAYLOAD BAY/RP-1 TANK SUPPORT	1	6500	6500	0.999901759	0.998910587	0.999901759	0.998910587	0.9333408	0.1234430
	PAYLOAD CONTAINER	1	1800	1800	0.999972794	0.998883411	0.999972794	0.998883411	0.2584680	0.0341848
	BASE HEAT SHIELD STRUCTURE	1	1043	1043	0.999984225	0.998867654	0.999984225	0.998867654	0.1498728	0.0198094
	BODY FLAP	1	751	751	0.999988642	0.998856308	0.999988642	0.998856308	0.1079064	0.0142614

Table 5 continued. WB001 Matrix Inputs & Outputs (Selected)

WB001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
INDUCED ENVIRONMENT	-	-	19572					0.0379848	0.0000000
TPS (FUSELAGE & WING)	22363	0.8	17890	0.999996403	0.998852716	0.999996403	0.998852716	60.4316496	58.0000000
INTERNAL INSULATION	1	969	969	0.999999999	0.998852715	0.999999999	0.998852715	0.0102312	58.0000000
PURGE, VENT & DRAIN	1	713	713	0.999996002	0.998848722	0.999996002	0.998848722	0.0379848	0.0000000
LANDING GEAR & AUXILIARY SYSTEMS	-	-	7018					0.7472640	0.0000000
NOSE GEAR	1	1041	1041	0.999999340	0.998848063	0.999999340	0.998848063	0.1108968	0.0000000
MAIN GEAR	2	2988.5	5977	0.999996212	0.998844279	0.999996212	0.998844279	0.6363672	0.0000000
PROPULSION, MAIN	-	-	52929	0.982680000	0.981544296	0.992780000	0.991632624	6.4360464	71.9876920
ENGINE (RD-704) & GIMBAL ACTUATORS	7	5820.28	40742	-	-	-	-	6.2616456	70.0370120
PRESSURIZATION & FEED SYSTEM	7	1399.57	9797	-	-	-	-	0.1739976	1.9461160
HELIUM PNEUMATIC & PURGE SYSTEM	7	341.43	2390	-	-	-	-	0.0004032	0.0045640
PROPULSION, RCS	-	-	3626.8					1.8789120	0.2481514
FORWARD MODULE	-	-	1087.6	See Note 1, Page 10				0.3670128	0.0485146
THRUSTER	1	48	48	1.000000000	0.981544296	1.000000000	0.991632624	0.1023792	0.0135280
PROPELLANT TANKAGE	1	413.7	413.7	1.000000000	0.981544296	1.000000000	0.991632624	0.0220584	0.0029146
VALVE	1	189.6	189.6	1.000000000	0.981544296	1.000000000	0.991632624	0.1263192	0.0167010
DISTRIBUTION & RECIRCULATION	1	436.3	436.3	1.000000000	0.981544296	1.000000000	0.991632624	0.1162560	0.0153710
AFT MODULE (2)	-	-	2539.2					1.5118992	0.1996368
THRUSTER	2	230	460	1.000000000	0.981544296	1.000000000	0.991632624	0.9824640	0.1296598
PROPELLANT TANKAGE	2	413.7	827.4	1.000000000	0.981544296	1.000000000	0.991632624	0.0441168	0.0058292
VALVE	2	189.6	379.2	1.000000000	0.981544296	1.000000000	0.991632624	0.2526384	0.0334020
DISTRIBUTION & RECIRCULATION	2	436.3	872.6	1.000000000	0.981544296	1.000000000	0.991632624	0.2326800	0.0307458
PROPULSION, OMS	-	-	2276	1.000000000	0.981544296	1.000000000	0.991632624	0.1094184	2.4300888
ENGINE (6000 LB THRUST EACH)	2	272.5	545	-	-	-	-	0.1089480	2.4195018
PROPELLANT TANK	1	740	740	-	-	-	-	0.0000336	0.0007296
PRESSURIZATION SYSTEM	1	991	991	-	-	-	-	0.0004368	0.0097774

Table 5 continued. WB001 Matrix Inputs & Outputs (Selected)

	WB001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
	PRIME POWER	-	-	2339					11.6628960	1.0528926
	FUEL CELL SYSTEM	-	-	2324					11.6307744	1.0500426
	FUEL CELL (270 VOLT)	4	222	888	0.999989364	0.981533856	0.999989364	0.991622076	11.2000056	1.0118640
	REACTANT DEWAR	4	359	1436	1.000000000	0.981533856	1.000000000	0.991622076	0.4307688	0.0381786
	BATTERY	1	15	15	0.999999691	0.981533553	1.000000000	0.991622076	0.0321216	0.0028500
	ELECTRICAL CONVERSION & DISTRIBUTION	-	-	6329					1.4914872	0.1322134
	POWER CONVERSION & DISTRIBUTION	1	1705	1705	0.999866038	0.981402065	0.999866038	0.991489237	0.4019064	0.0356174
	POWER DISTRIBUTION & CONTROL	1	1355	1355	0.999893542	0.981297587	0.999893542	0.991383685	0.3193848	0.0283062
	AVIONIC CABLING	1	1906	1906	0.999850279	0.981150666	0.999850279	0.991235254	0.4491984	0.0398164
	RCS CABLING	1	62	62	0.999995133	0.981145890	0.999995133	0.991230429	0.0145992	0.0012958
	OMS CABLING	1	193	193	0.999984844	0.981131020	0.999984844	0.991215406	0.0454608	0.0040318
	EMA CABLING	1	103	103	0.999991913	0.981123086	0.999991913	0.991207390	0.0242592	0.0021508
	CONNECTOR PLATE	1	207	207	0.999983749	0.981107142	0.999983749	0.991191282	0.0487536	0.0043244
	WIRE TRAYS	1	474	474	0.999982791	0.981070636	0.999982791	0.991154401	0.1116360	0.0099028
	EMA CONTROL UNIT	1	324	324	0.999974569	0.981045686	0.999974569	0.991129195	0.0762888	0.0067678
	CONTROL SURFACE ACTUATION	-	-	1285					1.0606008	0.0671042
	ELEVON	1	746	746	0.999949452	0.980996096	0.999949452	0.991079095	0.6153840	0.0389576
	TIP FIN	1	291	291	0.999980258	0.980976729	0.999980258	0.991059530	0.2403408	0.0151962
	BODY FLAP	1	248	248	0.999983171	0.980960220	0.999983171	0.991042851	0.2048760	0.0129504
	AVIONICS	-	-	1314	See Note 1, Page 10				2.9399832	0.2608358
	GUIDANCE, NAVIGATION & CONTROL	3	82.7	248.1	1.000000000	0.980960220	1.000000000	0.991042851	0.6436752	0.0570076
	COMMUNICATIONS & TRACKING	3	125.7	377.1	1.000000000	0.980960220	1.000000000	0.991042851	0.9767520	0.0866514
	INSTRUMENTATION SYSTEM	3	120.3	360.9	1.000000000	0.980960220	1.000000000	0.991042851	0.9333408	0.0829274
	DATA PROCESSING	3	109.3	327.9	1.000000000	0.980960220	1.000000000	0.991042851	0.3862152	0.0342494
	ENVIRONMENTAL CONTROL	-	-	2394					7.7207760	0.6819822
	EQUIPMENT COOLING	2	279.5	559	0.999999202	0.980959438	0.999999202	0.991042060	1.7872344	0.1592428
	HEAT TRANSPORT LOOP	2	632.5	1265	0.999995811	0.980955329	0.999995811	0.991037909	4.0975536	0.3603616
	HEAT REJECTION SYSTEM	-	-	570					1.8359880	0.1623778
	RADIATORS	2	181	362	0.999999660	0.980954995	0.999999660	0.991037572	1.1666592	0.1031244
	FLASH EVAPORATOR	2	104	208	0.999999888	0.980954885	0.999999888	0.991037461	0.6693288	0.0592534
	SSTO WB001 TOTALS =	-	-	174664.8	0.980954885	0.980954885	0.991037461	0.991037461	44.9566992	78.2962962
									Including TPS =	136.2962962

Table 6. Summary Matrix Outputs for VL001

VL001 REUSABLE LAUNCH VEHICLE Matrix INPUTS/OUTPUTS (1/25/95)	INPUT IN SHADED AREA
OPERATIONAL INPUTS ...	
RD-704 BURN TIME (HRS) =	0.120
FLIGHT DURATION (HRS) =	168.000
FLIGHT NO. (1 - 20+) =	20
Not Used =	2
OMS BURN TIME (HRS) =	0.140
VL001 SUMMARY OUTPUTS ... (Note: Flight-based excludes TPS Tiles/Blankets)	
UMAs/MISSION (FLIGHT-BASED) =	56.27
REMOVALS/MISSION (FLIGHT-BASED) =	12.39
FAILURES/MISSION (FLIGHT-BASED) =	22.50
TOTAL OPF-INDUCED PRs/FLOW (INCLUDING TPS) =	193
TOTAL OPF-INDUCED FAILURES/FLOW =	8
FAILURES/MISSION (LAUNCH PAD) =	1.90
TPS DEBRIS IMPACT REPAIRS/MISSION =	68
TPS PRs PER FLOW =	58
UNSCHEDULED MANHOURS PER FLOW =	5,151
SCHEDULED MANHOURS PER FLOW =	1,391
VL001 RLV ESTIMATED RELIABILITY	
PROBABILITY OF MISSION SUCCESS =	0.97712
PROBABILITY OF SAFE LANDING =	0.98776

Table 7. VL001 Matrix Inputs & Outputs (Selected)

VEHICLE	VL001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
WING GROUP		-	-	-						-
EXPOSED WING SURFACE		-	-	-	-	-	-	-	-	-
CARRY-THROUGH		-	-	-	-	-	-	-	-	-
TAIL GROUP		-	-	-						-
FIN		-	-	-	-	-	-	-	-	-
BODY GROUP		-	-	83055					11.9376096	1.5773382
LH2 TANK		-	-	16364					2.3588208	0.3107792
STRUCTURE	1	14383	14383	0.999781700	0.999781700	0.999781700	0.999781700	2.0740776	0.2731554	
INSULATION	1	1981	1981	0.999970027	0.999751734	0.999970027	0.999751734	0.2847432	0.0376238	
RP-1 TANK		-	-	3055					0.4386480	0.0580184
STRUCTURE	1	3055	3055	0.999953828	0.999705573	0.999953828	0.999705573	0.4386480	0.0580184	
LO2 TANK		-	-	16481					2.3594760	0.3129984
STRUCTURE	1	15049	15049	0.999773305	0.999478945	0.999773305	0.999478945	2.1538440	0.2858018	
INSULATION	1	1432	1432	0.999978355	0.999457311	0.999978355	0.999457311	0.2056320	0.0271966	
BASIC STRUCTURE		-	-	26027					3.7466352	0.4942926
NOSE SECTION (INCLUDING FLAPS)	1	769	769	0.999988366	0.999445683	0.999988366	0.999445683	0.1105272	0.0146034	
INTERTANK	1	8211	8211	0.999875471	0.999321223	0.999875471	0.999321223	1.1831064	0.1559406	
THRUST STRUCTURE CONE	1	9035	9035	0.999862922	0.999184238	0.999862922	0.999184238	1.3023192	0.1715890	
AFT BODY FAIRING	1	8012	8012	0.999878883	0.999063220	0.999878883	0.999063220	1.1506824	0.1521596	
SECONDARY STRUCTURE		-	-	21128					3.0340296	0.4012496
PAYLOAD BAY DOOR	1	675	675	0.999989790	0.999053020	0.999989790	0.999053020	0.0970032	0.0128212	
PAYLOAD BAY SUPPORT STRUCTURE	1	6500	6500	0.999901759	0.998954872	0.999901759	0.998954872	0.9333408	0.1234430	
PAYLOAD CONTAINER	1	2025	2025	0.999969352	0.998924256	0.999969352	0.998924256	0.2911608	0.0384560	
BASE STRUCTURE	1	3058	3058	0.999953707	0.998878013	0.999953707	0.998878013	0.4397904	0.0580754	
BODY FLAP & LANDING GEAR FINS	1	8870	8870	0.999866038	0.998744201	0.999866038	0.998744201	1.2727344	0.1684540	
INDUCED ENVIRONMENT PROTECTION		-	-	21418					0.0209328	0.0000000
TPS (BLANKETS, INSULATION, ETC.)	25079	0.8	20063	0.999995966	0.998740172	0.999995966	0.998740172	67.7692680	58.0000000	
INTERNAL INSULATION	1	962	962	0.999997977	0.998738152	0.999997977	0.998738152	0.0192192	0.0000000	
PURGE, VENT & DRAIN SYSTEM	1	393	393	0.999997796	0.998737971	0.999997796	0.998737971	0.0209328	0.0000000	

Table 7 continued. VL001 Matrix Inputs & Outputs (Selected)

VL001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
LANDING GEAR & AUXILIARY SYSTEMS	-	-	11410					0.4565232	0.0000000
LANDING GEAR	1	11410	11410	0.999997283	0.998735257	0.999997283	0.998735257	0.4565232	0.0000000
PROPULSION, MAIN	-	-	73499.2	0.979820000	0.978580780	0.989918000	0.988666008	10.9498200	124.0244480
ENGINE (RD-704) & GIMBAL ACTUATORS	8	7083.1	56664.8	-	-	-	-	10.8226440	121.0518320
PRESSURIZATION & FEED SYSTEM	8	1601.4	12811.2	-	-	-	-	0.1268400	2.9649000
DESCENT PROPELLANT TANKS	1	928	928	-	-	-	-	0.0000336	0.0008280
HELIUM PNEUMATIC & PURGE SYSYTEM	8	386.9	3095.2	-	-	-	-	0.0003024	0.0068880
PROPULSION, RCS	-	-	4030					5.0999592	0.6765064
THRUSTERS & SUPPORTS	-	-	508	See Note 1, Page 10				2.9008560	0.3859090
FORWARD	1	48	48	1.000000000	0.978580780	1.000000000	0.988666008	0.2758560	0.0364648
AFT	1	460	460	0.999999992	0.978580772	0.999999992	0.988666000	2.6250000	0.3494442
TANKS, VALVES & DISTRIBUTION	-	-	3522					2.1991032	0.2905974
LH2 TANK	1	1317	1317	1.000000000	0.978580772	1.000000000	0.988666000	0.1891848	0.0250116
LO2 TANK	1	327	327	1.000000000	0.978580772	1.000000000	0.988666000	0.0469728	0.0062092
VALVE	1	569	569	1.000000000	0.978580771	1.000000000	0.988666000	1.0243968	0.1350786
DISTRIBUTION & RECIRCULATION	1	1309	1309	1.000000000	0.978580771	1.000000000	0.988665999	0.9385488	0.1242980
PROPULSION, OMS	-	-	2871	1.000000000	0.978580771	1.000000000	0.988665999	0.2953440	6.5587696
ENGINE (6000 LB THRUST EACH)	2	272.5	545	-	-	-	-	0.2936304	6.5207126
PROPELLANT TANKS (LH2 & LO2)	1	994	994	-	-	-	-	0.0001176	0.0026410
PRESSURIZATION SYSTEM	1	1332	1332	-	-	-	-	0.0015960	0.0354160
PRIME POWER	-	-	2339.4					11.5397016	1.0419942
FUEL CELL SYSTEM	-	-	2324.4					11.5075800	1.0391442
FUEL CELL (270 VOLT)	4	222	888	0.999425539	0.978018614	0.999997313	0.988663342	11.2000056	1.0118640
LH2 REACTANT DEWAR	4	239.8	959.2	0.999897316	0.000000000	0.999897316	0.000000000	0.2053800	0.0182172
LO2 REACTANT DEWAR	4	119.3	477.2	0.999948906	0.977968643	0.999948906	0.988612828	0.1021944	0.0090630
BATTERY	1	15	15	0.999999691	0.977968341	1.000000000	0.988612828	0.0321216	0.0028500

Table 7 continued. VL001 Matrix Inputs & Outputs (Selected)

VL001 REUSABLE LAUNCH VEHICLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
ELECTRICAL CONVERSION & DISTRIBUTION	-	-	7241					1.7057040	0.1512666
POWER CONVERSION & DISTRIBUTION	1	1705	1705	0.999866038	0.977837330	0.999866038	0.988480391	0.4019064	0.0356174
POWER DISTRIBUTION & CONTROL	1	1355	1355	0.999893542	0.977733232	0.999893542	0.988375159	0.3193848	0.0283062
AVIONIC CABLING	1	1908	1908	0.999850279	0.977586844	0.999850279	0.988227179	0.4491984	0.0398582
RCS CABLING	1	62	62	0.999995133	0.977582087	0.999995133	0.988222369	0.0145992	0.0012958
OMS CABLING	1	193	193	0.999984844	0.977567270	0.999984844	0.988207392	0.0454608	0.0040318
EMA CABLING	1	267	267	0.999979042	0.977546782	0.999979042	0.988186681	0.0628824	0.0055784
CONNECTOR PLATE	1	207	207	0.999983749	0.977530896	0.999983749	0.988170622	0.0487536	0.0043244
WIRE TRAYS	1	474	474	0.999962791	0.977494523	0.999962791	0.988133853	0.1116360	0.0099028
EMA CONTROL UNIT	1	1070	1070	0.999916046	0.977412459	0.999916046	0.988050895	0.2518824	0.0223516
CONTROL SURFACE ACTUATION	-	-	4246					3.5142744	0.2217414
NOSE FLAP	1	919	919	0.999937559	0.977351428	0.999937559	0.987989200	0.7601832	0.0479940
BODY FLAP	1	3327	3327	0.999773796	0.977130347	0.999773796	0.987765713	2.7540912	0.1737474
AVIONICS	-	-	1314	See Note 1, Page 10				2.9399832	0.2608358
GUIDANCE, NAVIGATION & CONTROL	3	82.7	248.1	1.000000000	0.977130347	1.000000000	0.987765713	0.6436752	0.0570076
COMMUNICATIONS & TRACKING	3	125.7	377.1	1.000000000	0.977130347	1.000000000	0.987765713	0.9767520	0.0866514
INSTRUMENTATION SYSTEM	3	120.3	360.9	1.000000000	0.977130347	1.000000000	0.987765713	0.9333408	0.0829274
DATA PROCESSING	3	109.3	327.9	1.000000000	0.977130347	1.000000000	0.987765713	0.3862152	0.0342494
ENVIRONMENTAL CONTROL	-	-	2444					7.8056832	0.6962284
EQUIPMENT COOLING	2	279.5	559	0.999999202	0.977129568	0.999999202	0.987764925	1.7872344	0.1592428
HEAT TRANSPORT LOOP	2	712	1424	0.999994858	0.977124543	0.999994858	0.987759846	4.5405360	0.4056576
HEAT REJECTION SYSTEM	-	-	461					1.4779128	0.1313280
RADIATORS	2	81.5	163	0.999999932	0.977124476	0.999999932	0.987759778	0.5233704	0.0464360
FLASH EVAPORATOR	2	149	298	0.999999772	0.977124254	0.999999772	0.987759553	0.9545424	0.0848920
SSTO VL001 TOTALS ==	-	-	213868	0.977124254	0.977124254	0.987759553	0.987759553	56.2655352	135.2091286
								Including TPS =	193.2091286

Table 8. Summary Matrix Outputs for Space Shuttle

SPACE SHUTTLE (Including SRB's & External Tank) Matrix INPUTS/OUTPUTS (12/9/94)	INPUT IN SHADED AREA
OPERATIONAL INPUTS ...	
SSME BURN TIME (HRS) =	0.138
FLIGHT DURATION (HRS) =	168.000
FLIGHT NO. (1 - 20+) =	20
MISSIONS/YEAR/VEHICLE =	2
OMS BURN TIME (HRS) =	0.140
SPACE SHUTTLE SUMMARY OUTPUTS ... (Note: Flight-based excludes TPS Tiles)	
UMAS/MISSION (FLIGHT-BASED) =	134.37
REMOVALS/MISSION (FLIGHT-BASED) =	35.64
FAILURES/MISSION (FLIGHT-BASED) =	58.04
TOTAL OPF-INDUCED PRs/FLOW (INCLUDING TILE PRs) =	2,282
TOTAL OPF-INDUCED FAILURES/FLOW =	58
FAILURES/MISSION (LAUNCH PAD) =	1.10
TILE DEBRIS IMPACT REPAIRS/MISSION =	143
TILE PRs PER FLOW =	1,450
UNSCHEDULED MANHOURS PER FLOW =	147,233
MATRIX MODEL'S ESTIMATED RELIABILITY FOR SHUTTLE	
PROBABILITY OF MISSION SUCCESS =	0.97983
PROBABILITY OF SAFE LANDING =	0.98477

Table 9. Space Shuttle Matrix Inputs & Outputs (Selected)

NASA SPACE SHUTTLE			QTY	UNIT WT	TOTAL WT	PROBABILITY OF	POMS	PROBABILITY OF	SAFE LANDING	UMAS/MISSION	PRs/FLOW
ORBITER				(lbs)	(lbs)	MISSION SUCCESS	CUMULATIVE	SAFE LANDING	CUMULATIVE	(FLIGHT BASED)	
WING GROUP			-	-	15702.0					3.1600800	20.8743500
EXPOSED WING SURFACE			1	13465.0	13465.0	0.999714811	0.999714811	0.999714811	0.999714811	2.7096720	17.9004700
CARRY-THROUGH			1	2237.0	2237.0	0.999952590	0.999667415	0.999952590	0.999667415	0.4504080	2.9738800
TAIL GROUP			-	-	2610.0					0.5250000	3.4697800
FIN			1	2610.0	2610.0	0.999944738	0.999612171	0.999944738	0.999612171	0.5250000	3.4697800
BODY GROUP			-	-	45705.3					9.2063832	60.7606700
BASIC STRUCTURE			-	-	39578.1					7.9715496	52.6151800
FORWARD FUSELAGE			1	8238.1	8238.1	0.999824924	0.999437163	0.999824924	0.999437163	1.6633680	10.9517900
CREW MODULE			1	6872.0	6872.0	0.999855058	0.999292302	0.999855058	0.999292302	1.3770456	9.1355800
MID FUSELAGE			1	11702.0	11702.0	0.999750958	0.999043437	0.999750958	0.999043437	2.3661960	15.5566300
AFT FUSELAGE - BODY			1	9198.1	9198.1	0.999805687	0.998849309	0.999805687	0.998849309	1.8461520	12.2280200
AFT FUSELAGE - THRUST STRUCTURE			1	3182.4	3182.4	0.999932505	0.998781892	0.999932505	0.998781892	0.6412224	4.2307300
FORWARD RCS MODULE			1	385.5	385.5	0.999991836	0.998773738	0.999991836	0.998773738	0.0775656	0.5124300
SECONDARY STRUCTURE			-	-	6127.2					1.2348336	8.1454900
PAYLOAD BAY DOOR			1	4653.6	4653.6	0.999901210	0.998675069	0.999901210	0.998675069	0.9385488	6.1865900
BASE HEAT SHIELD STRUCTURE			1	1009.2	1009.2	0.999978642	0.998653740	0.999978642	0.998653740	0.2028936	1.3415900
BODY FLAP			1	464.4	464.4	0.999990170	0.998643923	0.999990170	0.998643923	0.0933912	0.6173100
INDUCED ENVIRONMENT (LESS TILES)			-	-	27477.5					12.7237152	21.1394000
TPS (TILES, BLANKETS, INSULATION, ETC.)			28000	0.8	22400.0	0.999999147	0.998643071	0.999999147	0.998643071	143.2225032	1450.0000000
THERMAL CONTROL SYSTEM			1	3390.9	3390.9	0.999429704	0.998073549	1.000000000	0.998643071	5.4193608	12.7102000
PURGE & VENT SYSTEM			1	1686.6	1686.6	0.999231417	0.997306446	0.999231417	0.997875531	7.3043544	8.4292000
LANDING GEAR & AUXILIARY SYSTEMS			-	-	6711.0					0.7148904	4.0247880
NOSE GEAR			1	954.8	954.8	0.999999394	0.997305842	0.999999394	0.997874926	0.1017576	0.5726220
MAIN GEAR			1	5756.2	5756.2	0.999996350	0.997302202	0.999996350	0.997871284	0.6131328	3.4521660
PROPULSION, MAIN			-	-	33405.3	0.991637720	0.988962482	0.995179999	0.993061543	13.3275912	132.0320670
ENGINE (SSME)			3	7038.0	21114.0	-	-	-	-	11.7171096	81.9118125
SSME GIMBAL SYSTEM			3	586.1	1758.3	-	-	-	-	0.5421024	3.7896275
ANCILLARY SYSTEM			3	1831.0	5493.0	-	-	-	-	0.7451640	5.2091375
PROPELLANT FEED SYSTEM			3	1680.0	5040.0	-	-	-	-	0.3232152	41.1214895

Table 9 continued. Space Shuttle Matrix Inputs & Outputs (Selected)

NASA SPACE SHUTTLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAS/MISSION (FLIGHT BASED)	PRs/FLOW
PROPULSION, RCS	-	-	3212.0					7.3885224	12.2200400
				See Note 1, Page 10					
REACTION CONTROL SYSTEM (FORWARD)	-	-	1530.2					3.3357240	5.4730450
THRUSTER (PRIME & VERNIER)	16	31.8	508.8	1.000000000	0.988962482	1.000000000	0.993061543	2.9473752	4.8314150
THRUSTER SUPPORT	1	359.4	359.4	1.000000000	0.988962482	1.000000000	0.993061543	0.0722904	0.1194625
PRESSURIZATION SYSTEM	1	148.0	148.0	1.000000000	0.988962482	1.000000000	0.993061543	0.2126544	0.3513575
PROPELLANT SYSTEM (FUEL)	1	265.3	265.3	1.000000000	0.988962482	1.000000000	0.993061543	0.0533736	0.0881600
PROPELLANT SYSTEM (OXIDIZER)	1	248.7	248.7	1.000000000	0.988962482	1.000000000	0.993061543	0.0500304	0.0826500
REACTION CONTROL SYSTEM (AFT)	-	-	1681.8					4.0527984	6.7469950
THRUSTER (PRIME & VERNIER)	28	21.5	602.0	1.000000000	0.988962482	1.000000000	0.993061543	3.4285776	5.7164350
PRESSURIZATION SYSTEM	1	329.0	329.0	1.000000000	0.988962482	1.000000000	0.993061543	0.4732392	0.7810425
PROPELLANT SYSTEM (FUEL)	1	379.2	379.2	1.000000000	0.988962482	1.000000000	0.993061543	0.0762552	0.1260175
PROPELLANT SYSTEM (OXIDIZER)	1	371.6	371.6	1.000000000	0.988962482	1.000000000	0.993061543	0.0747264	0.1235000
PROPULSION, OMS	-	-	3087.0	0.999999999	0.988962480	0.999999999	0.993061542	2.4784368	48.8984275
ENGINE & ACTUATORS	2	319.3	638.6	-	-	-	-	2.4575040	43.0860900
PRESSURIZATION SYSTEM	2	379.5	759.0	-	-	-	-	0.0064848	1.8018175
FUEL SYSTEM	2	420.1	840.2	-	-	-	-	0.0071904	1.9945725
OXIDIZER SYSTEM	2	424.6	849.2	-	-	-	-	0.0072576	2.0159475
PRIME POWER	-	-	6988.3					16.7822592	22.2973220
POWER GENERATION, CONTROL & DISTRIBUTION	-	-	6785.3					14.6004432	20.7755120
FUEL CELL	3	261.7	785.0	0.999107607	0.988079937	0.999994779	0.993056357	9.8823480	4.4724860
POWER REACTANT STORAGE/DIST (OXYGEN)	4	201.0	804.0	0.999873120	0.987954569	0.999873120	0.992930358	0.2410296	0.1068940
POWER REACTANT STORAGE/DIST (HYDROGEN)	4	216.0	864.0	0.999863756	0.987819966	0.999863756	0.992795078	0.2588544	0.1148550
INVERTER	9	80.0	720.0	0.999971605	0.987791917	0.999971605	0.992766887	0.6562584	0.2905670
POWER CONTROL ASSEMBLY	3	200.4	601.2	0.999999994	0.987791911	0.999999994	0.992766881	1.0306800	4.5670300
MOTOR CONTROL ASSEMBLY	3	88.1	264.3	0.999999999	0.987791911	0.999999999	0.992766881	0.4528272	2.0077300
MASTER EVENT CONTROL	3	43.3	129.9					0.2225160	0.9868600
MAIN DISTRIBUTION BOX	3	61.3	183.9	1.000000000	0.987791911	1.000000000	0.992766881	0.3152016	1.3970700
LOAD CONTROL ASSEMBLY	3	93.0	279.0	1.000000000	0.987791911	1.000000000	0.992766881	0.4772712	2.1194500
ELECTRICAL DISTRIBUTION SYSTEM	3	180.3	540.9	1.000000000	0.987791911	1.000000000	0.992766881	0.5793144	2.5680400
ELECTRICAL SUPPORTS & INSTALLATION	3	537.7	1613.1	1.000000000	0.987791911	1.000000000	0.992766881	0.4841424	2.1445300
EXTERIOR/INTERIOR LIGHTS	1	203.0	203.0	1.000000000	0.987791911	1.000000000	0.992766881	2.1818160	1.5218100

Table 9 continued. Space Shuttle Matrix Inputs & Outputs (Selected)

NASA SPACE SHUTTLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
AUXILIARY POWER SYSTEM	-	-	862.1	0.999543100	0.987340588	0.999543100	0.992313285	2.8705824	18.8499430
APU POWER UNIT	3	125.2	375.5	-	-	-	-	1.2502728	8.2103630
APU FUEL SYSTEM	1	335.1	335.1	-	-	-	-	1.1158392	7.3270120
APU LUBE OIL COOLANT LOOP	1	46.9	46.9	-	-	-	-	0.1561728	1.0254755
APU EXHAUST SYSTEM	1	82.7	82.7	-	-	-	-	0.2753688	1.8082470
APU WATER SYSTEM	1	21.9	21.9	-	-	-	-	0.0729288	0.4788455
ELECTRICAL CONVERSION & DISTRIBUTION	-	-	7309.5					6.8290656	30.3137400
EPD&C CABLING	1	2151.4	2151.4	0.999410700	0.986758749	0.999410700	0.991728515	2.3013648	10.2145900
INSTRUMENTATION CABLING	1	1430.6	1430.6	0.999608468	0.986372401	0.999608468	0.991340222	1.5272712	6.7923100
GN&C CABLING	1	683.4	683.4	0.999812727	0.986187680	0.999812727	0.991154570	0.7304304	3.2446300
COMMUNICATIONS & TRACKING CABLING	1	376.4	376.4	0.999896684	0.986085791	0.999896684	0.991052168	0.4028808	1.7871400
FORWARD RCS CABLING	1	28.9	28.9	0.999992066	0.986077967	0.999992066	0.991044305	0.0309456	0.1371800
AFT RCS CABLING	1	54.4	54.4	0.999985063	0.986063238	0.999985063	0.991029502	0.0582456	0.2582100
OMS CABLING	1	275.6	275.6	0.999924327	0.985988620	0.999924327	0.990954508	0.2952600	1.3085300
DATA PROCESSING CABLING	1	308.3	308.3	0.999915411	0.985905216	0.999915411	0.990870684	0.3300528	1.4637600
CONNECTOR	1	106.5	106.5	0.999970758	0.985876386	0.999970758	0.990841709	0.1140552	0.5055900
WIRE TRAY	1	591.6	591.6	0.999837694	0.985716373	0.999837694	0.990680890	0.6339648	2.8087700
PAYLOAD DOOR CABLING	1	18.0	18.0	0.999995059	0.985711502	0.999995059	0.990675995	0.0192696	0.0855000
CABLING INSTALLATION & SUPPORT	1	1284.4	1284.4	0.999901239	0.985614153	0.999901239	0.990578154	0.3853248	1.7075300
CONTROL SURFACE ACTUATION	-	-	2716.5					10.1190600	32.2439500
ELEVON	1	1099.2	1099.2	0.999915857	0.985531220	0.999915857	0.990494804	4.0975536	13.0471100
RUDDER SPEED BRAKE	1	1256.6	1256.6	0.999904171	0.985436778	0.999904171	0.990399886	4.6666704	14.9153800
BODY FLAP	1	360.7	360.7	0.999972178	0.985409361	0.999972178	0.990372331	1.3548360	4.2814600
AVIONICS	-	-	6368.7	See Note 1, Page 10				20.0228280	35.7110675
GUIDANCE, NAVIGATION & CONTROL	3	322.3	966.9	1.000000000	0.985409360	1.000000000	0.990372331	4.2000000	1.8737230
COMMUNICATIONS & TRACKING	3	478.9	1436.7	0.999999999	0.985409359	0.999999999	0.990372330	6.2222160	9.2315790
DISPLAYS & CONTROLS	3	718.7	2156.1	1.000000000	0.985409359	1.000000000	0.990372329	4.3076880	1.1495055
INSTRUMENTATION SYSTEM	3	237.2	711.6	1.000000000	0.985409359	1.000000000	0.990372329	3.1111080	13.7898200
DATA PROCESSING	3	365.8	1097.4	1.000000000	0.985409359	1.000000000	0.990372329	2.1818160	9.6664400
ENVIRONMENTAL CONTROL	-	-	5264.0					16.8891072	33.5429550
CABIN & PERSONNEL SYSTEM	-	-	2120.0					6.7908288	13.5089650
TANKS, VALVES & PLUMBING	2	227.6	455.2	0.999999927	0.985409287	0.999999927	0.990372257	1.4608776	2.9006250
ATMOSPHERIC REVITALIZATION SYSTEM	2	291.6	583.2	0.999999881	0.985409169	0.999999881	0.990372139	1.8666648	3.7162000
HEAT TRANSPORT WATER LOOP	2	165.5	331.0	0.999999961	0.985409131	0.999999961	0.990372100	1.0632888	2.1091900
EQUIPMENT ENVIRONMENTAL CONTROL LOOP	2	375.3	750.6	0.999999803	0.985408936	0.999999803	0.990371905	2.3999976	4.7829500

Table 9 continued. Space Shuttle Matrix Inputs & Outputs (Selected)

NASA SPACE SHUTTLE	QTY	UNIT WT (lbs)	TOTAL WT (lbs)	PROBABILITY OF MISSION SUCCESS	POMS CUMULATIVE	PROBABILITY OF SAFE LANDING	SAFE LANDING CUMULATIVE	UMAs/MISSION (FLIGHT BASED)	PRs/FLOW
EQUIPMENT ENVIRONMENT/HEAT TRANSPORT	-	-	3144.0					10.0982784	20.0339900
HEAT TRANSPORT FREON LOOP	2	1538.4	3076.8	0.999996671	0.985405656	0.999996671	0.990368608	9.8823480	19.6057600
AMMONIA SYSTEM	2	33.6	67.2	0.999999998	0.985405655	0.999999998	0.990368607	0.2159304	0.4282300
HYDRAULIC CONVERSION & DISTRIBUTION	-	-	1854.0					11.3333304	2.4285420
HYDRAULIC POWER SUPPLY EQUIPMENT	1	201.0	201.0	0.999999999	0.985405654	0.999999999	0.990368606	3.9999960	0.8588950
HYDRAULIC DISTRIBUTION & CONTROL	1	1053.2	1053.2	0.999999999	0.985405653	0.999999999	0.990368605	4.6666704	1.0000840
HYDRAULIC TEMPERATURE CONTROL SYSTEM	1	599.8	599.8	1.000000000	0.985405653	1.000000000	0.990368604	2.6666640	0.5695630
A. ORBITER	-	-	169273.2	0.985405653	0.985405653	0.990368604	0.990368604	134.3708520	478.8070420
B. SOLID ROCKET BOOSTER	2	192000.0	384000.0	0.994345942	0.979834112	0.994345942	0.984769003	-	195.0000000
C. EXTERNAL TANK	1	66000.0	66000.0	1.000000000	-	1.000000000	-	-	158.0000000
				0.979834112	0.979834112	0.984769003	0.984769003		831.8070420
								PLUS TILES =	2281.8070420

SIMtrix outputs for the WB001 indicate the elapsed time expended on the vehicle for maintenance (each flight). Downtime is measured as the elapsed time from start of the first task to completion of the last, including off-shift time and weekends. The case illustrated is highly optimistic since the assumption that all work can be conducted concurrently fails to consider that accessibility and safety constraints limit the size of the work force that can be on, in, or around the vehicle at the same time. Figure 5 addresses the matter of accessibility. Under the assumption that the direct labor force consists of 50 maintenance technicians, mean downtime equals 24 days (working 1 shift per day, 5 days per week).

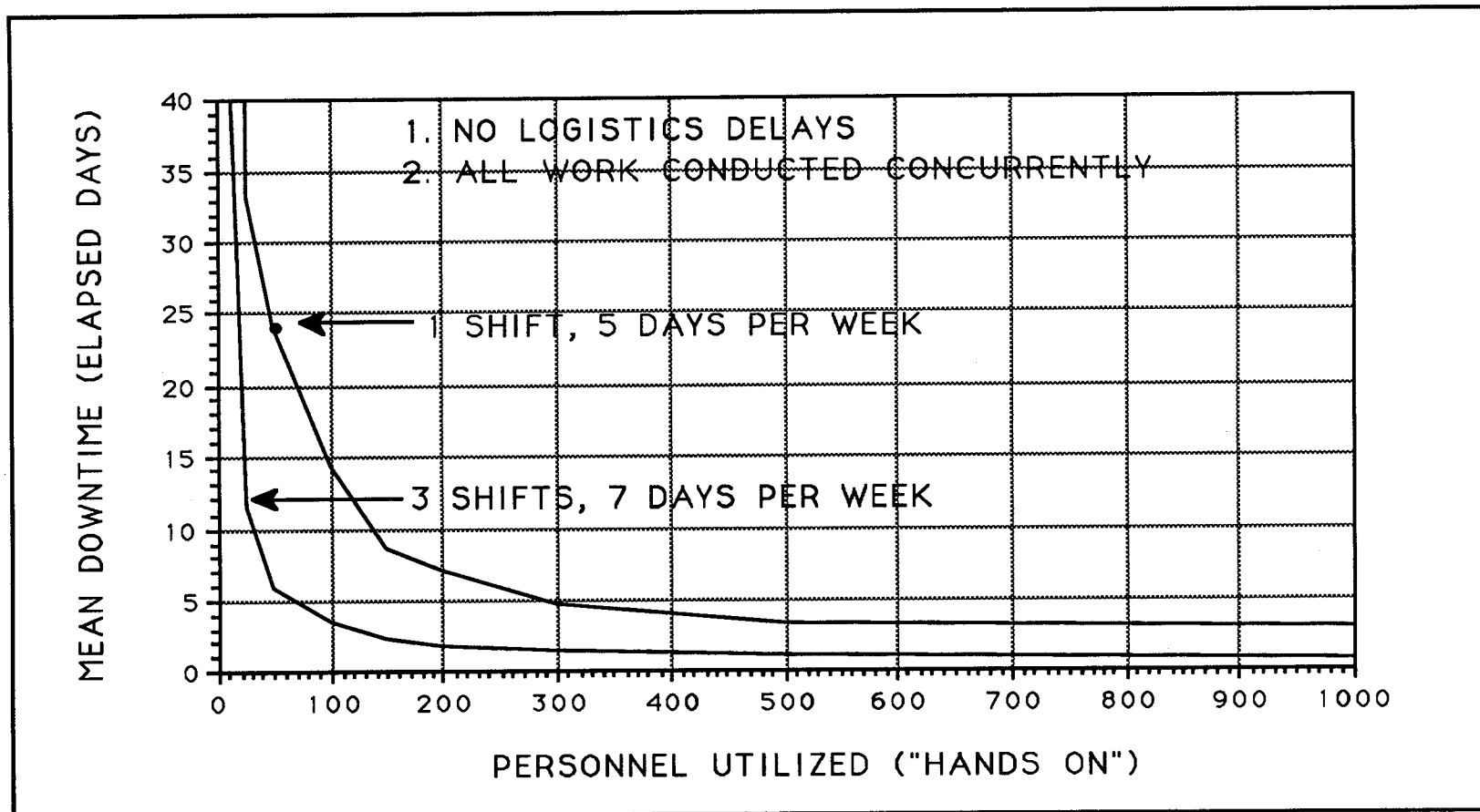


Figure 3. WB001 Mean Downtime

SIMtrix outputs for the VL001 indicate the elapsed time expended on the vehicle for maintenance (each flight). Downtime is measured as the elapsed time from start of the first task to completion of the last, including off-shift time and weekends. The case illustrated is highly optimistic since the assumption that all work can be conducted concurrently fails to consider that accessibility and safety constraints limit the size of the work force that can be on, in, or around the vehicle at the same time. Figure 5 addresses the matter of accessibility. Under the assumption that the direct labor force consists of 50 maintenance technicians, mean downtime equals 28 days (working 1 shift per day, 5 days per week).

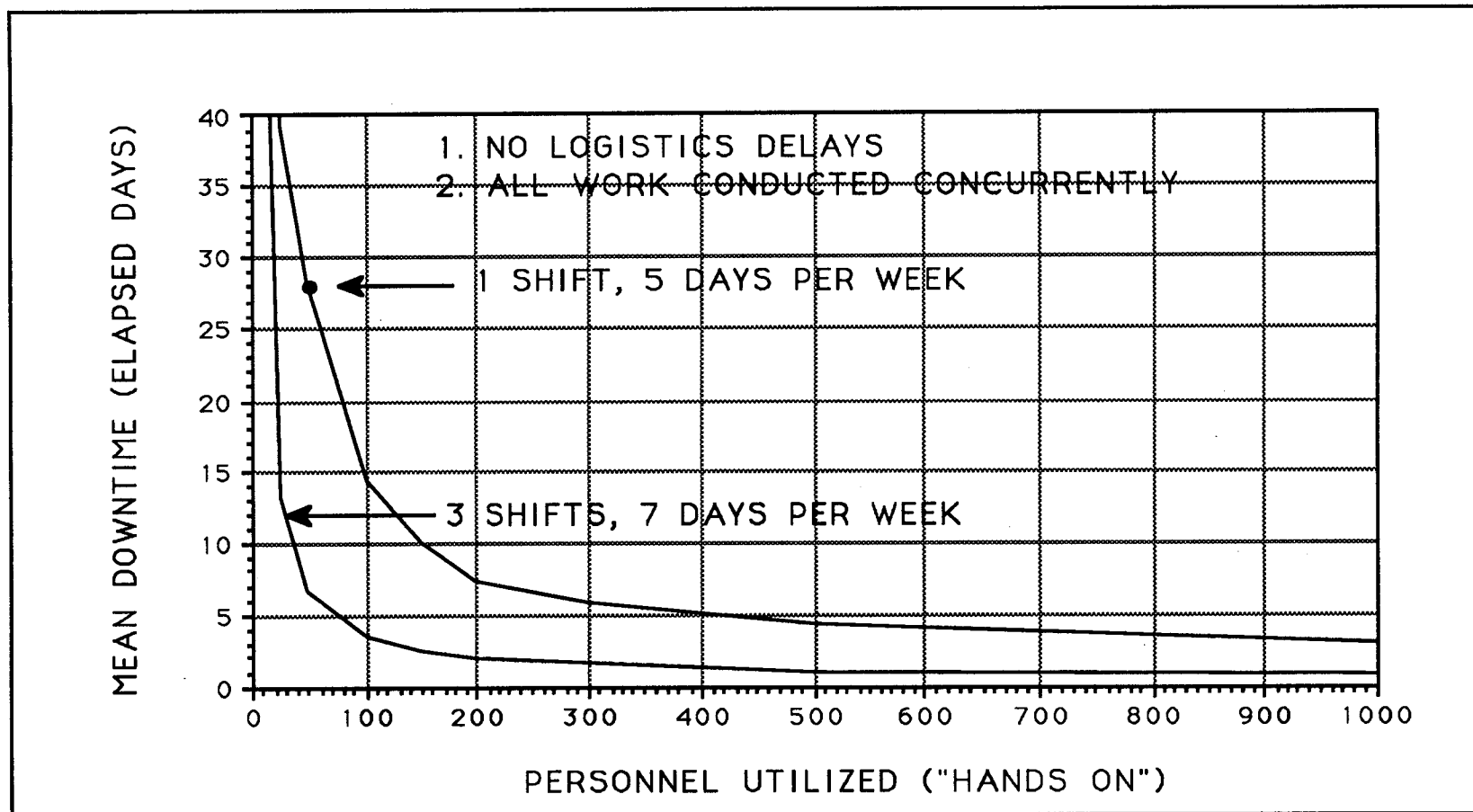


Figure 4. VL001 Mean Downtime

Accessibility to all components requiring maintenance is an important design attribute. For RLVs to achieve low maintenance & rapid turnaround it is essential that aircraft-type accessibility be provided. To further emphasize the need for maximum accessibility consider the following. Aircraft typically undergo searching inspections at intervals of about 200 flying hours. In preparation for such inspections all required access doors & panels are opened, enabling the maximum number of technicians to simultaneously conduct the needed inspections, & to correct any observed discrepancies. The 200 hour aircraft inspection interval roughly corresponds to only 1 flight of an RLV (i.e., 168 hours for a 7 day flight). Aircraft-type downtime can be realized only if aircraft-type access is provided.

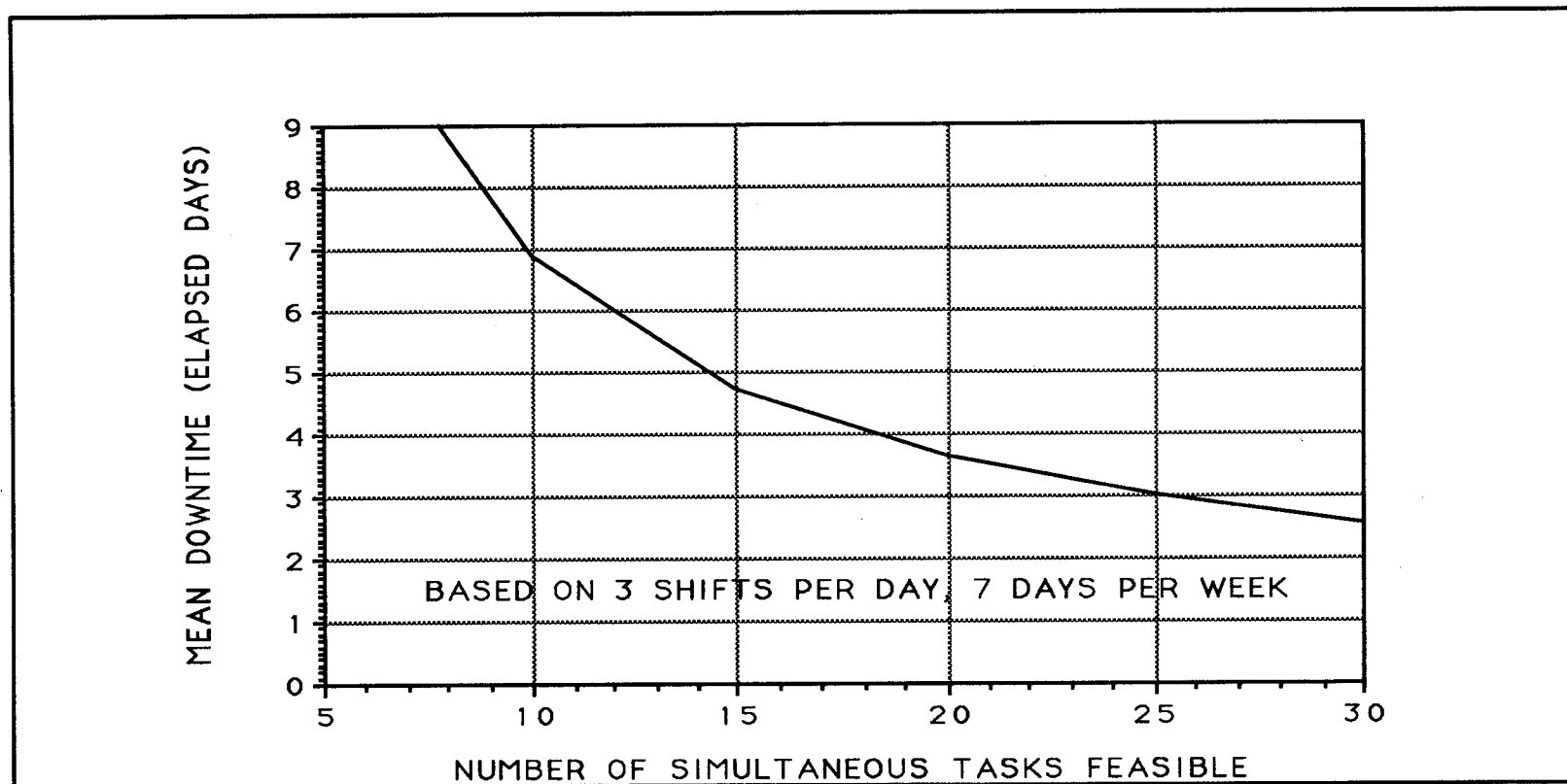


Figure 5. How Design Features Such As Accessibility Influence Downtime

LAUNCH FACILITY UTILIZATION

STARSIM, Rockwell's Facility Analysis Tool, was employed to determine if stated facility capacities would be adequate to support 30 RLV flights per year. The following assumptions were made:

1. Ground processing time per flight is 24 days (1 shift, 5 days per week).
2. A Horizontal Ground Processing Facility is employed for non-hazardous scheduled & unscheduled maintenance tasks.
3. All vehicles remain in the Ground Processing Facility until moved to the launch pad.
4. Pad processing time is 1 day per launch (2 work shifts per day).
5. Pad refurbishment is 6.75 days.

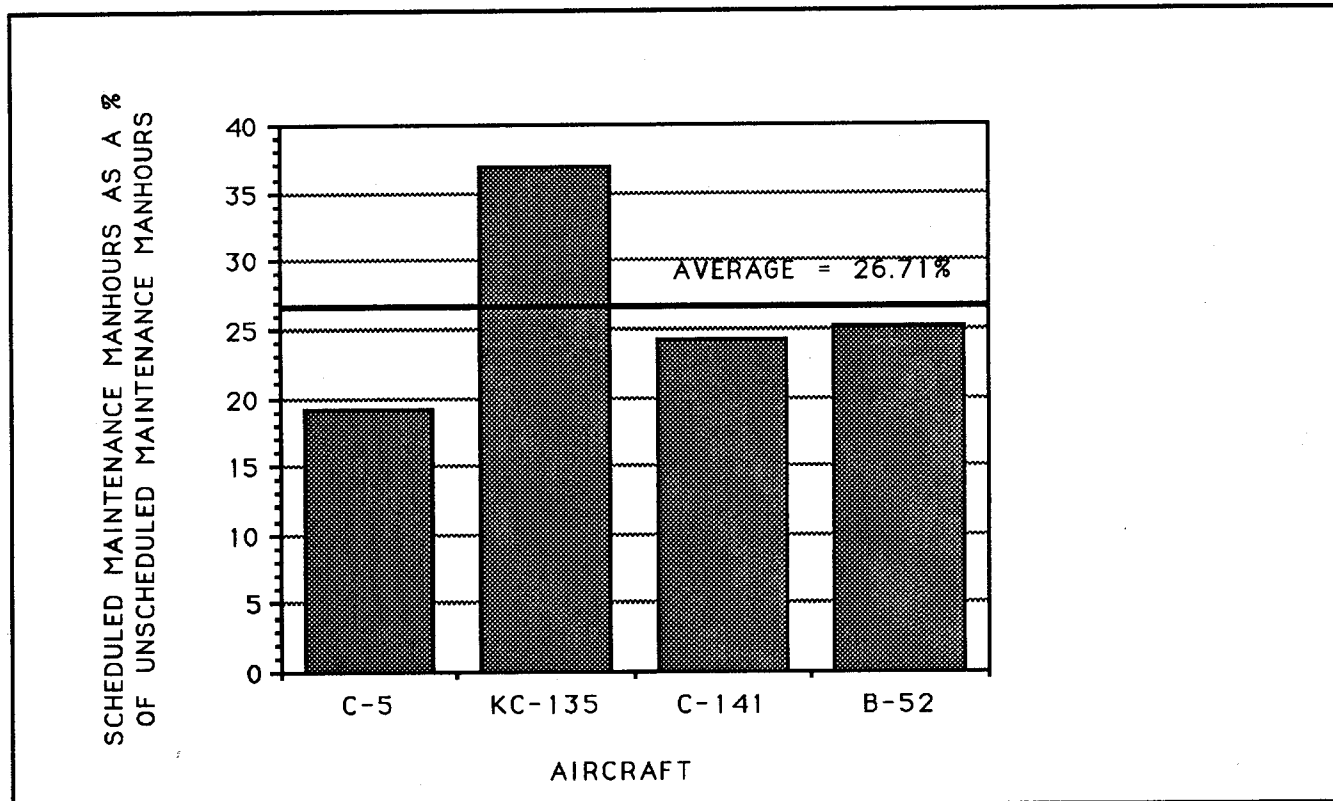
Results of this analysis are presented below as Table 10.

Table 10, Launch Facility Utilization

FACILITY	FACILITY QTY/ CAPACITY	PERCENT UTILIZED	RANGE 95% C.L.
Horizontal Processing	1 @ 5 Vehicles	76.0	75.8 - 76.3
Erector	3 each	51.8	51.7 - 51.9
Launch Pad	2 each	49.5	49.2 - 50.0

Figure 6 presents, for large multi-engined aircraft, how scheduled maintenance manhours and unscheduled maintenance manhours are related. The aircraft depicted are mature, and their scheduled maintenance programs are well-established. Generally, these scheduled maintenance programs follow the principles of RCM (Reliability Centered Maintenance). The below percentages were derived from a large data sample (1,184,700 flying hours and a total of 19,507,000 scheduled and unscheduled maintenance manhours). Scheduled maintenance manhours, as used herein, encompass the manhours expended for the "look phase" of scheduled inspections (Work Unit Code 03), and the manhours associated with the scheduled replacement of components. Note: Servicing manhours have not been included in this analysis.

Figure 6. Scheduled Maintenance Manhours as a Percentage of Unscheduled Maintenance Manhours



Analysis of Allocated Ground Processing Turnaround Timeline

The MSFC-furnished Ground Processing Turnaround Timeline for the Winged Body configuration allocated a total of 12 8-hour shifts for all ground processing activities. The timeline encompassed all events from landing at KSC to launch on the next mission.

Times allocated for events such as Runway Operations, Safing & Deservicing, Payload Removal, etc. appear to be reasonable and probably achievable. For Subsystems Maintenance and Checkout a total of 38 hours (4.75 shifts) were allocated and, further, the originator of the timeline assumed that; all LRUs would be easily accessible, all LRUs would utilize self-test capability, and that maximum use of Vehicle Health Management techniques would be made. Based on the potential post-flight maintenance workloads expected for a large, complex, 7-engined vehicle such as WB001, 38 hours is insufficient time to conduct the necessary systems maintenance and checkout while, at the same time, preserving the vehicle's inherent reliability.

By comparison, Orbiter ground processing requires 60 to 70 days, and "power-on" times for systems checkout often exceeds 1,000 hours. Referring to the EXCEL-based R&M Model provided separately for the Shuttle, the column entitled OPF HRS/CYCLES (Column AO) provides an estimate, by system and where feasible, by component, of actual power-on times. Similarly, the columns entitled OPF HRS/CYCLES (Column AP) of the WB001 and VL001 R&M Models indicate that power-on times will be significantly less than those of Shuttle (i.e., approximately 50 hours for WB001 & VL001 compared to 1,000 for Shuttle). These greatly reduced power-on times will accrue as a result of an exhaustive Reliability Centered Maintenance analysis effort, and full exploitation of the self-test and Vehicle Health Management technologies.

As indicated in Figures 3 and 4, estimated maintenance times (mean downtimes) for WB001 and VL001 are 24 and 28 days respectively. It is reasonable to assume that the approximately 50 hours of power-on time for checkout are encompassed by the times indicated. It is therefore suggested that the 38 hours originally allocated for subsystems maintenance and checkout of the Winged Body SSTO be revised to 192 hours (i.e., 24 x 8), or 24 shifts. This modification to the original timeline has the effect of increasing the total timeline (encompassing landing to launch) from 12 shifts to 31.25 shifts.